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Fatigue Failure of a Distortion Screen during Testing

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Abstract

A distress was observed in a distortion screen during testing. This screen is positioned in front of an aero engine during testing to check the engine performance with a distorted air intake. To ensure a distorted air intake, the screen contains dense meshes in some areas whereas in other areas they are less dense. Non-uniformity in the mesh density results in distorted air flow into the engine thereby facilitating evaluation of the engine performance with disturbed aerodynamic inlet. The component, i.e. the distortion screen was under development and was subjected to aerodynamic tests on the test bench. It was found to have fractured from a rib connecting two meshes. Loose end of the mesh had detached and resulted in permanent deformation of the adjoining ribs and meshes. The fractured surface exhibited glossy crystalline appearance. Scanning electron microscope revealed striations at higher magnifications (>500X) as was observed in the case of fatigue failure. Two crack fronts were adjacent and near to one corner of the rib, and the third crack front had originated from the other corner placed diagonally opposite to the other two crack fronts. This observation indicated failure of the screen under reverse bending fatigue condition. Design and material condition were reviewed. After modification it was found that the newly modified distortion screen did not show any sign of deformation after testing.

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Keywords: Gas turbine engine; fatigue; striations; strain gage; reverse bending fatigue

1. Introduction

Gas turbine engines are the power plants for the aircrafts. Performance of these engines are strongly influenced by the distorted inlet flow of air through an air intake duct placed in front during the complex mission cycles of the aircraft [1, 2]. This often leads to non-uniform air intake throughout the cross section of the engine which may result in aerodynamic disturbance into the system and results in catastrophic failure [3]. To ensure acceptable engine performance with a distorted air in-flow, distortion screens are placed in front of the engine and tested [4] as shown in Fig. 1. The differential sizes of meshes in the screen are designed to allow a non-uniform air in-take into the engine.

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This paper describes about the failure analysis of the “Inlet flow distortion screen”, which was damaged during structural testing. The screen was made up of a ferritic grade stainless steel. The component was manufactured from 5mm thick sheet by water jet cutting.

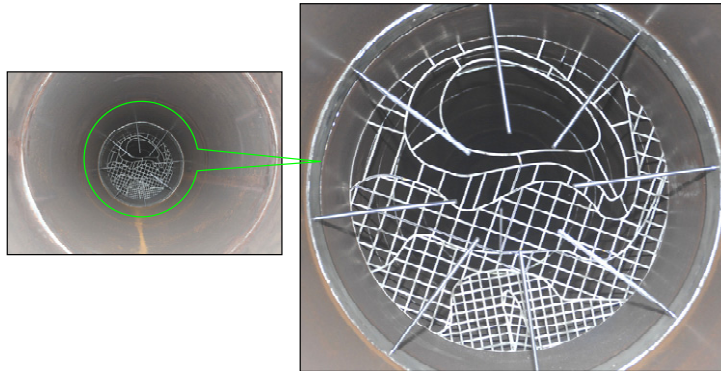


Fig. 1. Photograph of the distortion screen assembled in the rig before the test.

2. Observations

2.1. Visual observations

The distortion screen got permanent deformation in the flow direction in the region where the grid size was maximum. It was found to have fractured from a rib joining two meshes (Fig. 2). Loose end of the mesh had come out & resulted in permanent deformation to the adjoining ribs & meshes. The fractured surface of the loose end revealed glossy crystalline appearance (Fig. 3). Traces of pink tints were noticed on the fractured surface indicating dye penetrant inspection (DPI) after failure.

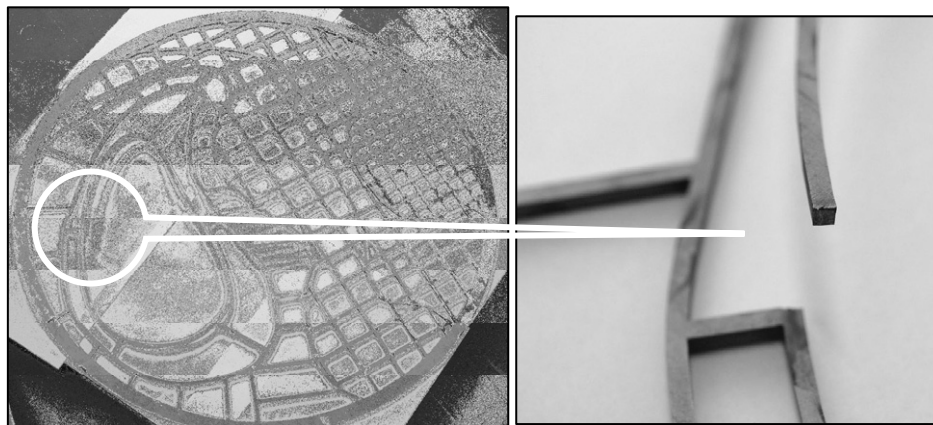


Fig. 2. Photograph of the failed distortion screen.

2.2. Observations under stereo microscope

The fractured portions were cut from the screen at suitable locations to study the mode of failure. The fractured surface of the loose end (refer Fig. 3) revealed post fracture damage (rubbing) on almost the entire surface. The fractured surface of the fixed end was less damaged comparatively. A step was noticed on the fractured surface indicating simultaneous propagation of two crack fronts (Fig. 3).

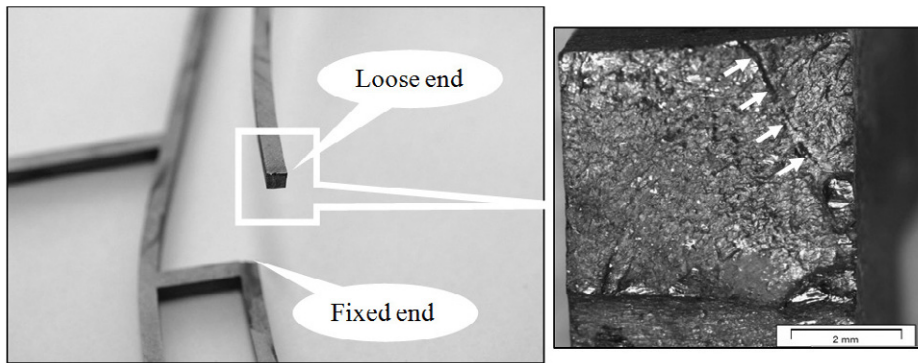


Fig. 3. Crystalline appearance of the fractured surface; arrows indicating step observed on fractured surface.

2.3. Scanning electron microscopy

Both the samples were cleaned using ultrasonic cleaner and studied using Scanning Electron Microscope (SEM). The fractured surface of the fixed end revealed striations at higher magnifications ($>500\times$) as was observed (Fig. 4) in case of fatigue failure [5]. Striations were noticed on almost entire fractured surface.

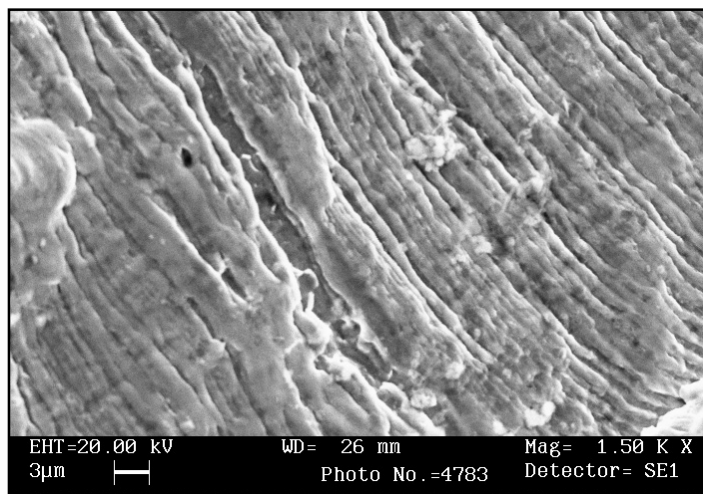


Fig. 4. Fatigue striations on the fractured surface of fixed end.

Tracing back the orientation of the crack fronts, three crack origins were found on the surface (Fig. 5). Two crack fronts were adjacent and near to one corner of the rib, and the other crack front had originated from the other corner placed diagonally opposite to the two crack fronts (refer Fig. 5).

However, all the edges of the fractured surface were damaged by post fracture rubbing and so details at the crack origins could not be studied. It may be noted here that a depression was noticed at the crack origin 3 (refer Fig. 5).

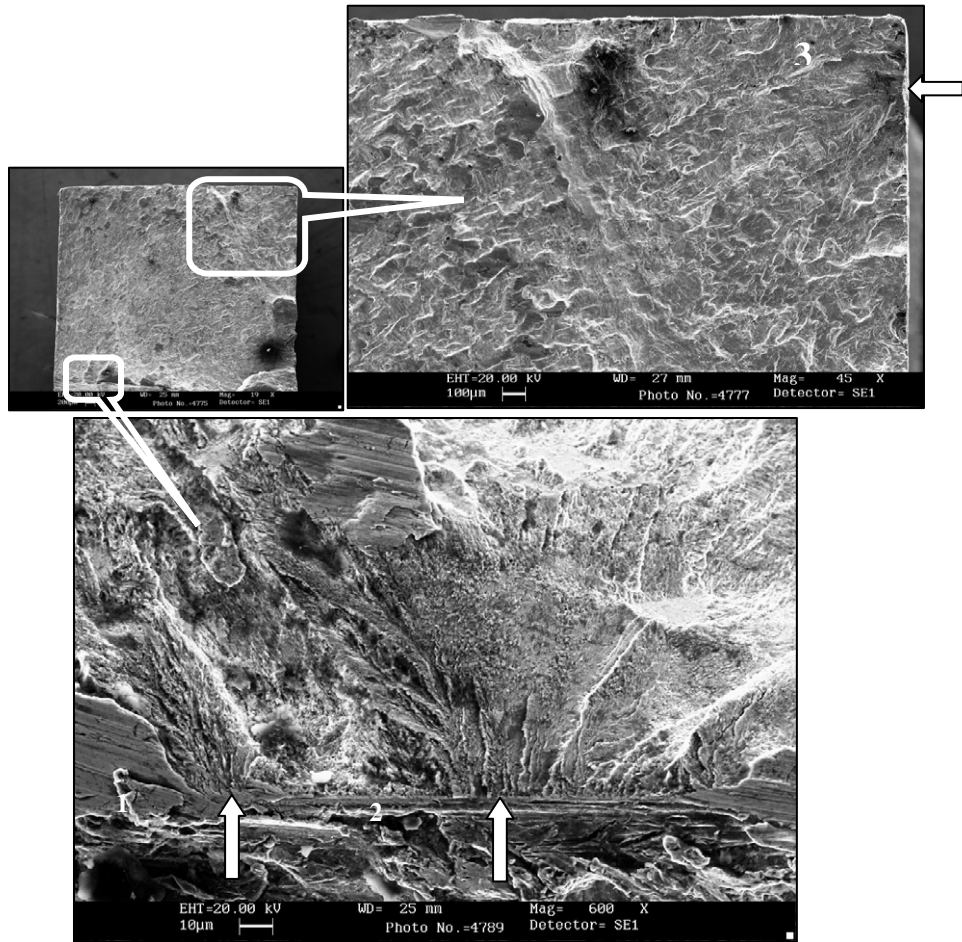


Fig. 5. Fractured surfaces at higher magnification; arrows point to the crack origins.

Semi-quantitative chemical analysis on the sample obtained from one of the ribs using EDAX revealed that material was conforming to ferritic grade stainless steel (refer table 1).

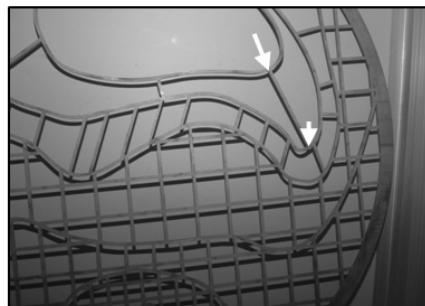


Fig. 6 Arrows showing location of cracks in the distortion screen after testing.

Two more cracks were noticed on the distortion screen at the ends of rib joining the fractured rib and other mesh (Fig. 6). One crack was on the front face of the screen and the other one was on the rear side. This may be attributed to the differential flexure of screen due to the complex geometry of the mesh.

3. Hardness measurements

Suitable sample was cut from the one of the ribs of the screen. Hardness measurement was carried out using Rockwell hardness tester. The hardness of the material was in the range of 72-75 R_b ($< 20R_c$) as expected for the material of construction.

4. Analysis

Fractographic features indicated that the screen has failed by fatigue crack initiation and propagation. The step on the fractured surface indicated presence of more than one crack front. High magnification SEM studies revealed three crack origins. Two crack fronts were adjacent and they were located diagonally opposite to the third crack front. Presence of the diagonally opposite crack fronts indicated failure by reverse bending fatigue, during which each crack got opened in one half cycle, closed and pressed together during the other half cycle, by virtue of which high points on opposite sides of fatigue crack got rubbed and polished [5].



Fig. 7. Configuration of the distortion screen; (a) previous configuration, (b) present configuration.

Presence of two more cracks at two opposite surfaces on the ribs adjacent to the fractured one further confirmed that the component was under reverse bending mode while testing. Subsequent testing of the distortion screens were also carried out with proper strain gauging on both the surfaces of the component. Further it was reported by the testing group that high strain values were recorded during the testing. Cracks were also identified in few locations of the distortion screen (on the front and rear face) after the testing. Therefore it was opined that the component was experiencing very high amount of alternating stresses during testing which has resulted in the failure of ribs.

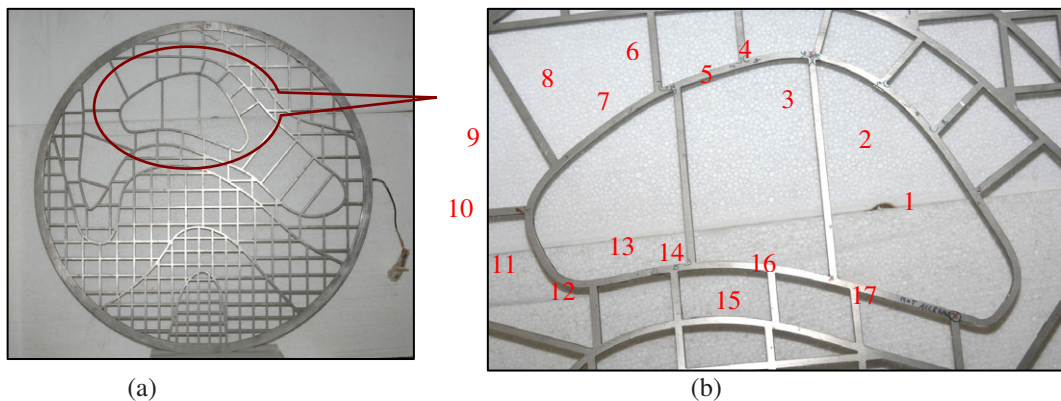


Fig. 8 a) Modified Distortion screen b) photograph showing critical portions in the screen.

5. Recommendations

Change of material and design modifications with adequate structural support were suggested. Subsequent to this analysis a new distortion screen was designed and tested. The design of this distortion screen was more stiff as compared to the previous distortion screen, as it is supported by additional rib joints in the critical portions. Figure 7 shows the changed design at the failure location of previous and corresponding location in the modified distortion screen.

After the test was completed visually no deformation was found on the screen (as found on previously designed distortion screen). The rib joints in the critical portions (previously where failures were noticed in the distortion screens) marked 1 to 17 (Fig. 8 (a) & (b)) were closely observed under stereomicroscope. None of these joints revealed any crack.

6. Conclusions

- The screen appeared to have failed by reverse bending fatigue mode. Moreover, since the material was found to be very soft (hardness < 20 R_c), adequacy of structural strength of the material for the application was also reconsidered.
- Failures have occurred at locations having larger grid size. The geometric features in this zone were reviewed and changes were made.
- Newly modified distortion screen which was supported by additional rib joints did not show any deformation along any critical points after testing.

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